Chapter 4
Trunnion Assembly

4-1. General Description

The structural engineer shall coordinate the design of the trunnion assembly with a qualified mechanical engineer. Design of lubrication systems, tolerance and finish requirements, material selection, and determination of allowable stresses should be coordinated with a mechanical engineer. The trunnion assembly provides support for the tainter gate while allowing for rotation for operational use.

a. Conventional system. The trunnion assembly is made up of a fixed trunnion yoke that is bolted to the trunnion girder, a trunnion hub, and a trunnion pin with a bushing or bearing. Bushings or bearings are provided to minimize friction and wear during rotation of the gate about the trunnion pin. The trunnion assembly is designed to transmit gate load directly to the trunnion girder. Figure 4-1 illustrates typical details for a cylindrical bushing assembly. Spherical bearings are generally more expensive than cylindrical bearings due to their complexity. However, spherical bearings will compensate for a degree of misalignment of gate arms, construction tolerances, thermal movement, and uneven gate lifting. When compared to cylindrical bearings, spherical bearings are generally more narrow and the use of spherical bearings reduces or eliminates stresses at the edge of the bearings, produces a more uniform pressure distribution over the trunnion pin, potentially reduces trunnion pin moments and gate arm stresses due to misalignment. Spherical bearings will accommodate an angular rotation transverse to the pin centerline in the range of 6 to 10 deg depending on bearing size. A tradeoff exists with the use of spherical bearings over cylindrical bushings in that the gate arms associated with spherical bearing are usually heavier due to an increased buckling length. Figure 4-2 shows a spherical bearing configuration.

b. Other systems. Center-mounted trunnions are commonly used in combination with steel box trunnion girders. The trunnion pin is supported at the geometric centroid of the girder by plates that are oriented perpendicular to the pin centerline. The pin can bear directly on the supporting plates or within a housing tube attached to the plates. Use of the tube provides for a more accurate bore for the pin. This arrangement can significantly reduce torsion applied to the trunnion girder since load eccentricity is reduced or eliminated. A center-mounted arrangement is described in Figure 4-3.

4-2. Structural Components

Figure 4-4 describes the layout of structural components.

a. Trunnion yoke. The yoke is typically fabricated of welded structural steel and consists of two parallel plates (yoke plates) that are welded to a stiffened base plate (Figure 4-5). The yoke plates are machined to receive the trunnion pin and associated components. The assembly is bolted to the trunnion girder after final installation adjustments have been made by horizontal and vertical jackscrews. Shear bars that are welded to the base plate may be required to resist shear at the interface with the trunnion girder for loads that produce resultant forces that are not normal to the bearing surface.

b. Trunnion hub. The hub can be fabricated of cast, forged, or structural steel. Castings and forged steel are typically more costly than welded steel construction. The inside bore is machined to tolerance for proper fit with the trunnion bushing or bearing. The hub is welded to the gate arm extensions and is joined to the yoke with the trunnion pin. The hub is typically wider than the gate arm extensions to allow

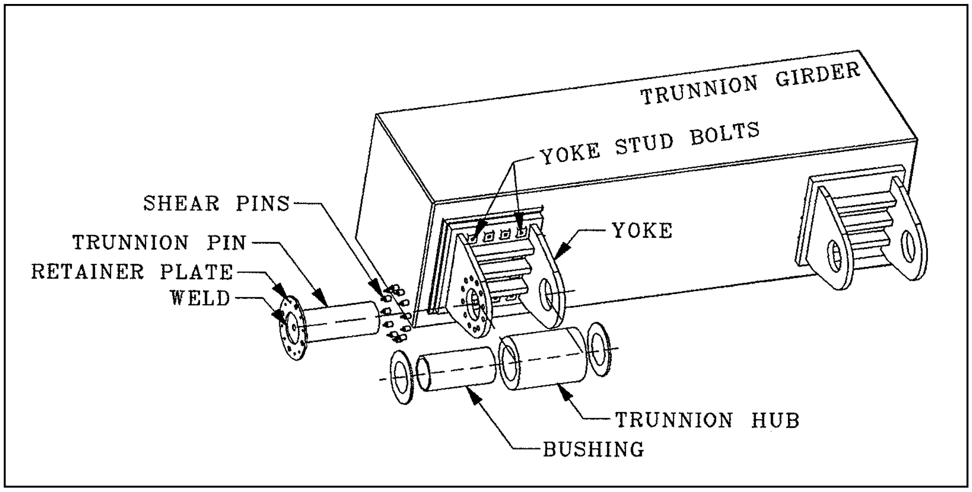

Figure 4-1. Trunnion assembly with cylindrical bushing

for a more uniform distribution of stress and to provide clearance for a welded connection. A bushing or bearing is provided between the hub and trunnion pin to reduce friction. The trunnion hubs and yokes shall be stress relieved by heat treatment and machined after fabrication welding is completed.

c. Trunnion pin. The trunnion pin transfers the gate loads from the hub to the yoke side plates. A retainer plate that is welded to the pin is fitted with shear pin to prevent the trunnion pin from rotating. The retainer plate and pin are connected to the yoke with a keeper plate.

d. Trunnion bushing. Bushings are provided between the trunnion pin and hub and between the hub and yoke plates. The bushings provide a uniform bearing surface and reduce torsional loads due to friction. The required thickness will depend on the size of the trunnion pin. However, to maintain a true shape during machining, bushings should be at least 12 mm (1/2 in.) thick. An interference fit is generally used between the hub and bushing.

e. Spherical plain bearings. Spherical plain bearings consist of an inner and outer ring and may contain intermediate sliding elements. The outer ring is fit within the trunnion hub and the inner ring is placed on the trunnion pin. The outer ring of the bearing is generally mounted inside the trunnion hub with an interference fit to prevent movement of ring seats. The inner ring may be mounted to the trunnion pin using an interference fit to prevent movement between the pin and the inner ring.

f. Anchorage. Bolts are used to attach the trunnion yoke to the trunnion girder. Consideration should be given to using partially prestressed high-strength stud bolts to minimize movement relative to the trunnion girder.

4-3. Material Selection

Material selection, surface finishes, dimensional tolerances, and allowable stresses shall be coordinated with a qualified mechanical engineer.

a. Trunnion hub. Material for trunnion hubs should be corrosion resistant, weldable, and machinable. The trunnion hub is typically machined from cast steel (ASTM A27) or forged steel (ASTM A668).

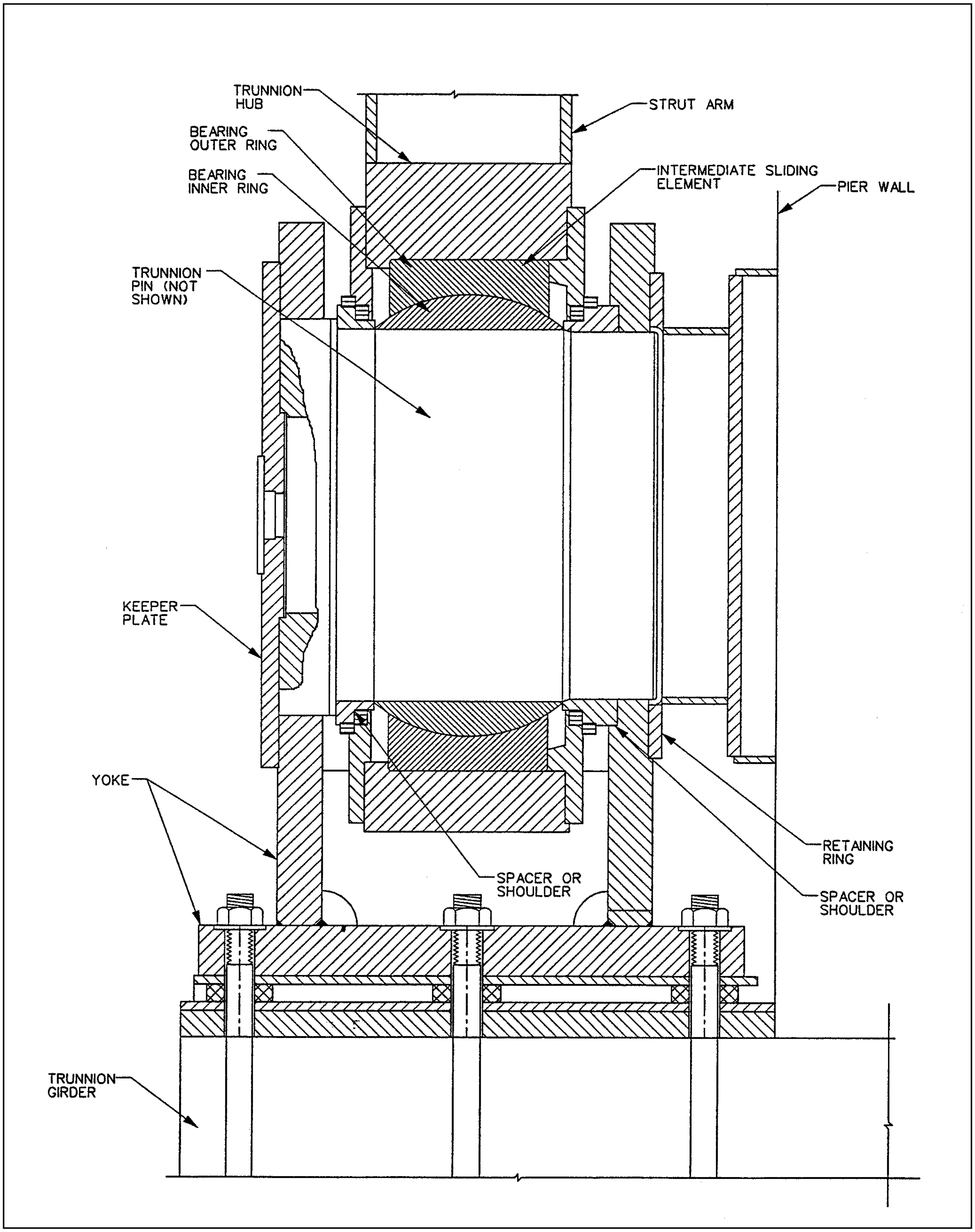

Figure 4-2. Spherical bearing

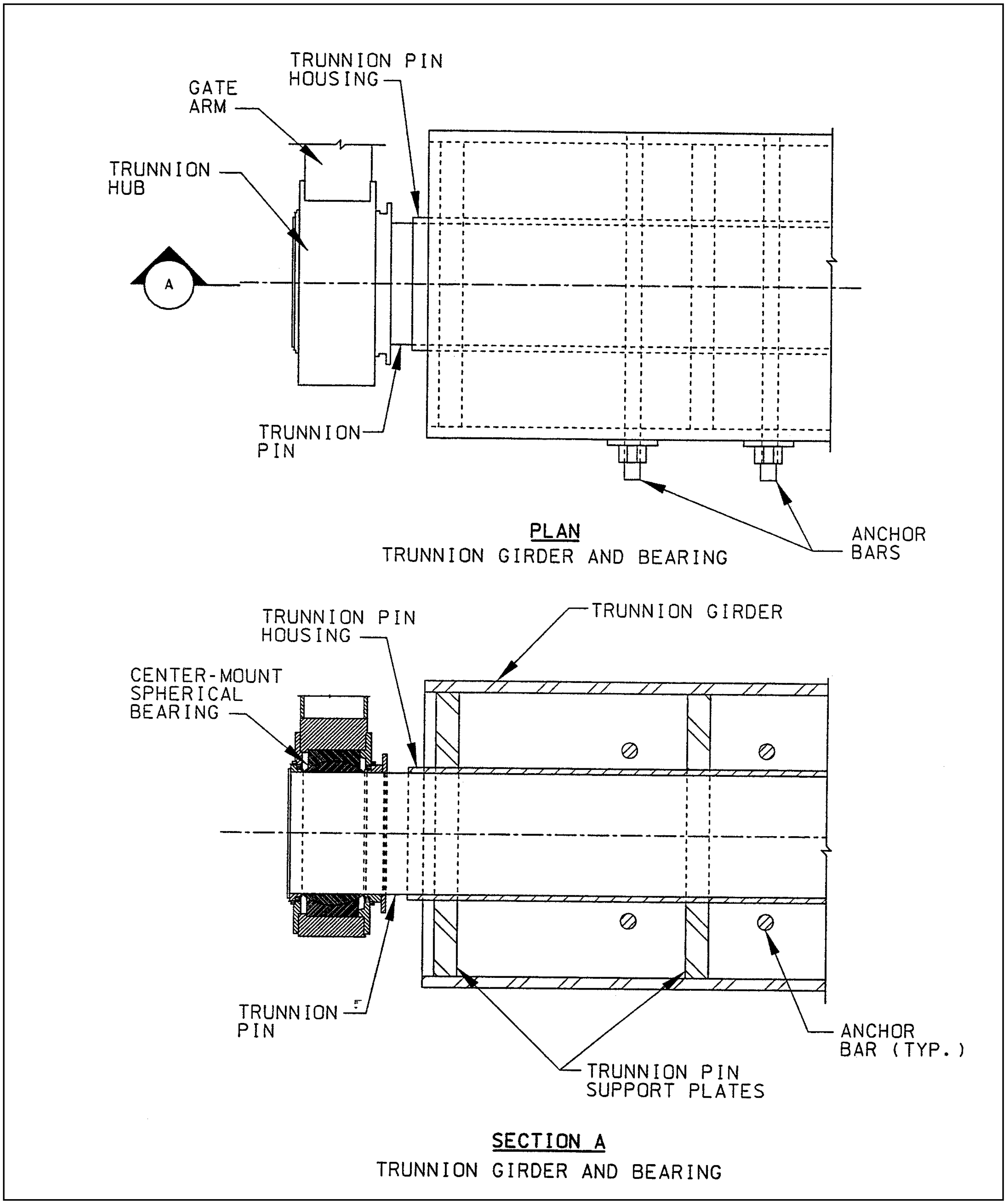

Figure 4-3. Center-pin mount bearing

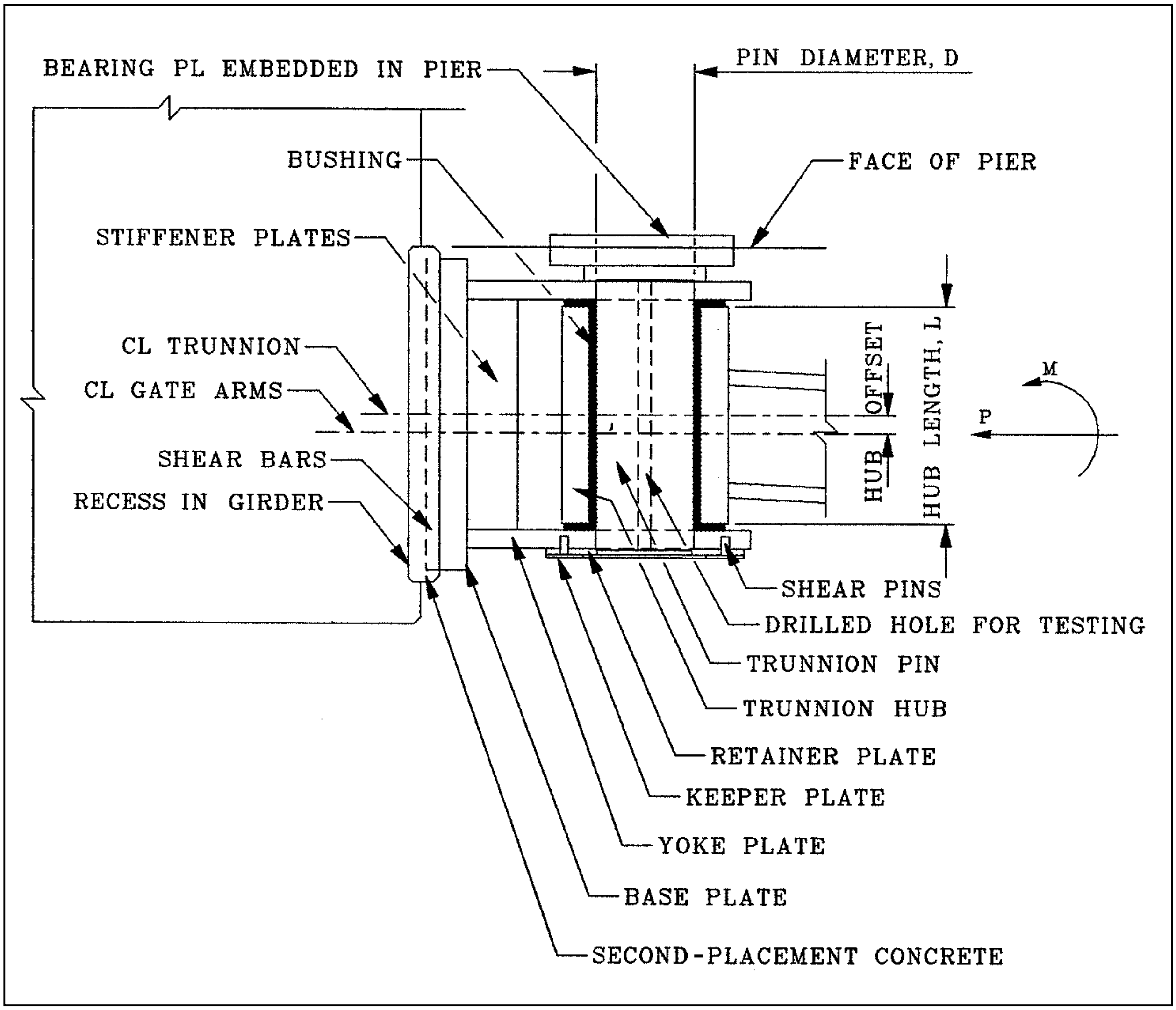

Figure 4-4. Trunnion assembly structural component layout

b. Trunnion bushing. Bushing materials are generally selected based on allowable bearing stresses, resistance to galling and coefficient of friction. Aluminum bronze (ASTM B148) is commonly used where bearing pressures do not exceed 35 MPa (5000 psi) and manganese bronze or self-lubricating bronze (ASTM B22-90a) is used for applications where bearing pressures up to 55 MPa (8000 psi) are required.

c. Spherical plain bearings. Spherical plain bearings are generally made of a high-strength carbon chromium steel treated with molybdenum disulfide. Maintenance free bearings may include a sinter-bronze composite or a poly-tetra-flouro-ethylene compound.

d. Trunnion yoke. The trunnion yokes are typically constructed of welded structural steel (ASTM A36 or A572) or cast steel (ASTM A27).

e. Stud bolts. Stud bolts, used to attach the trunnion yoke to the trunnion girder, are usually made from high-strength alloy steel conforming to ASTM A722 or ASTM A354.

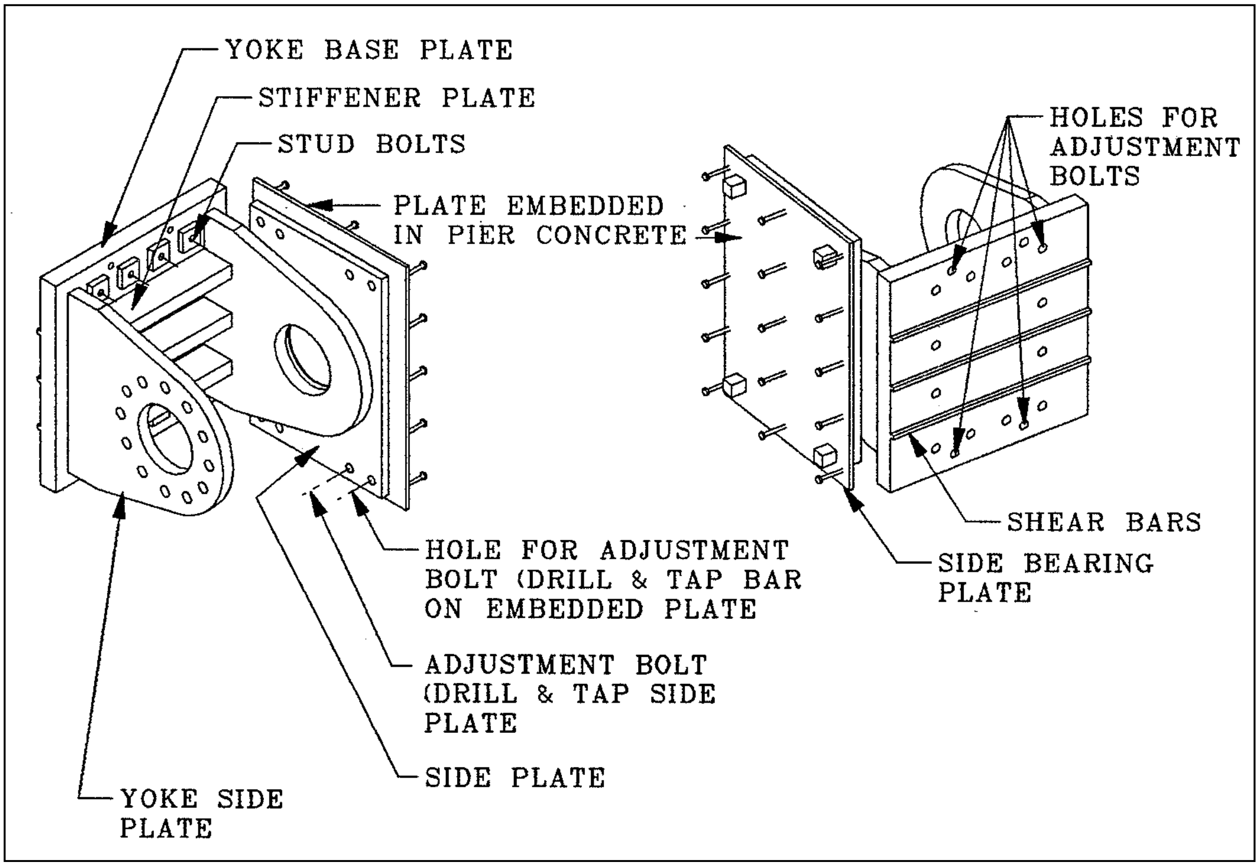

Figure 4-5. Typical trunnion yoke assembly

f. Trunnion pin. The material used for the trunnion pin must be compatible with the bushing material and be capable of high quality finishes to minimize friction. The trunnion pins shall be made from corrosion-resistant steel such as forged steel conforming to ASTM A705, Type 630, Condition H 1150. Historically, a carbon steel forging such as ASTM A668 was coated with a stainless steel weldment with subsequently machining. This practice is becoming less economical due to intensive labor costs.

g. Shear pins. Material for shear pins should corrosion resistant and machinable. The shear pins are typically machined from cast or forged steel conforming to ASTM A276.

h. Retainer and keeper plate. Material for the retainer and keeper plates should corrosion resistant, weldable, and machinable. The retainer and keeper plates can be fabricated from material conforming to ASTM A240, type 304.

4-4. Design Requirements

a. Design basis. All components of the trunnion assembly shall be designed based on allowable stress design. Maximum allowable working stresses for forgings and casting shall be limited to $0.5F_y$

where F_y is the material yield stress.

Allowable stresses and tolerances for bearings and bushings shall be established by the mechanical engineer. Serviceability requirements are specified in paragraph 4-6.

b. Load requirements. The trunnion assembly shall be designed for load combinations specified in Chapter 3 except a uniform load factor of 1.0 shall be applied to all sources of loading. Torsional loads due to trunnion pin friction shall be based on a coefficient of friction consistent with materials utilized (see paragraph 3-4.b(1)(f). The bearing stress between the yoke base plate and the trunnion girder should include both the pre-tensioning force of the anchorage stud bolts and global gate reaction forces.

4-5. Analysis and Design

Due to frictional resistance developed at the trunnion pin with gate movement, the design of the trunnion assembly affects the end frame design and the required hoist capacity (paragraphs 3-4 and 3-5). The centerline of bearing of the trunnion hub is commonly offset with respect to the centerline of the gate arms (Figure 4-4). This offset is recommended so that a uniform bearing stress distribution occurs under maximum loading (gate is nearly closed and impact and silt loads are applied). Other load conditions will produce nonuniform bearing stresses on the trunnion pin and bushing and must be investigated individually. The transfer of forces between the trunnion pin, retainer plate, shear pins, and yoke shall be considered in design.

a. Bushing. The bushing is designed as a boundary lubricated bearing. The bushing is proportioned such that the actual bearing stresses do not exceed allowable stresses. The bearing pressure between the trunnion pin and bushing is based on an effective area and the gate reaction forces. The effective bearing area is commonly based on the dimensions of the projected width of the trunnion pin onto the bushing (or bearing). The magnitude of bearing pressure is dependent on the length and diameter of the trunnion pin. The contact pressure is assumed to act uniformly across the diameter of the trunnion pin (even though it is theoretically nonuniform).

b. Spherical plain bearing. Design of the bearing is based on the strength of the bearing material. Serviceability requirements (limiting wear or deformations) are specified in paragraph 4-6. Material strength will usually control the design of tainter gate trunnion bearings because frequency of gate operation is relatively low. Bearing size is a function of direction and magnitude of trunnion reactions. Spherical bearings transmit radial forces (loads acting primarily in plane perpendicular to axis of trunnion pin) and moderate axial forces simultaneously (loads acting in a plane parallel to the axis of the trunnion pin). Where axial forces are large, thrust washers or an additional thrust bearing may be required to transmit axial loads.

c. Trunnion pin. The trunnion pin is designed as a simply supported beam with supports located at the centerlines of the yoke plates. Loading consists of the bearing stresses from the bearing or bushing. The length and diameter of the trunnion pin shall be proportioned such that the bearing pressure onto the bushing and flexural and shear stresses in the trunnion pin are less than the allowable stress limits as discussed in paragraph 4-3. The bearing, flexural and shear stresses are calculated using commonly accepted engineering practices. The retainer plate and shear pins are designed to carry frictional loads produced when the tainter gate is raised or lowered. The magnitude of torsion produced by friction is a function of the trunnion pin diameter, the coefficient of friction and the magnitude of the gate thrust. The weld connecting the retainer plate to the trunnion pin shall be sized to prevent rotation (see Figure 4-6). For spherical bearings, bearing movement occurs between the inner and outer rings only and not on the pin. Therefore, the pin is designed only to support the bearing inner ring.

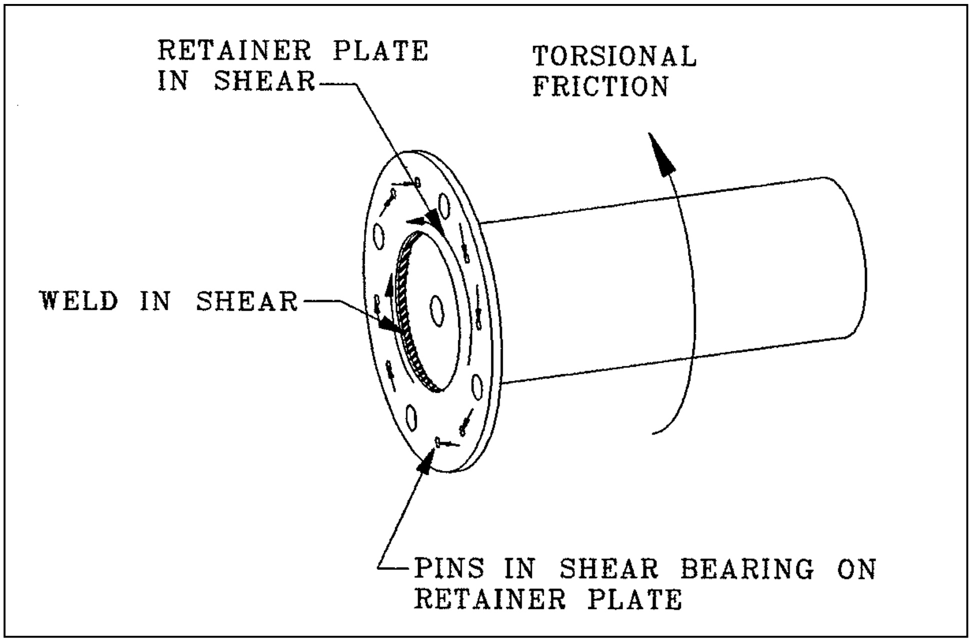

Figure 4-6. Generalized forces on trunnion pin and retainer plate

d. Yoke. The yoke side plate shall be sized to resist trunnion pin bearing load and lateral gate loads. The base plate and stiffeners shall be designed to resist contact pressure between the yoke bearing plate and trunnion girder based on gate reaction forces and stressing loads imposed by steel stud bolts, as shown by Figure 4-7. To determine the required strength, it is recommended that the base plate be analyzed as a simple beam supported by the parallel yoke plates with a distributed load equal to the bearing pressure.

e. Trunnion hub. The trunnion hub can be modeled as a cantilevered beam subjected to a distributed load from the trunnion pin as shown in Figure 4-8. The cantilevered portion of hub extends beyond the flange of the trunnion arm extension. Design checks for bending and horizontal shear are made along section A-A of Figure 4-8.

4-6. Serviceability Requirements

a. Access. The design shall consider features such as ladders, foot stands, railing, and passageways for access to the trunnion assembly for inspection and maintenance purposes.

b. Grease systems. Except where self-lubricating bearings are used, provisions to grease and lubricate the trunnion pin shall be provided. Manual or automatic grease systems may be used. Grease fittings are provided on the hub for both manual and automated systems. For automated delivery systems the grease fittings provided in the trunnion hub or through the trunnion pin to allow for lubrication in event of a pump failure. Automated grease systems dispense a measured amount of grease to the trunnion automatically at intervals established by the mechanical engineer. Provisions to flush automated systems should be considered. Pump units should be located near the trunnion to minimize grease line length. Grease lines should be stainless steel pipe of adequate wall thickness for the anticipated pressures.

c. Lubrication. Steel-on-steel bearings require lubrication at regular intervals. Lubricants that contain rust-inhibiting compounds are desirable. Lubrication should be considered for some

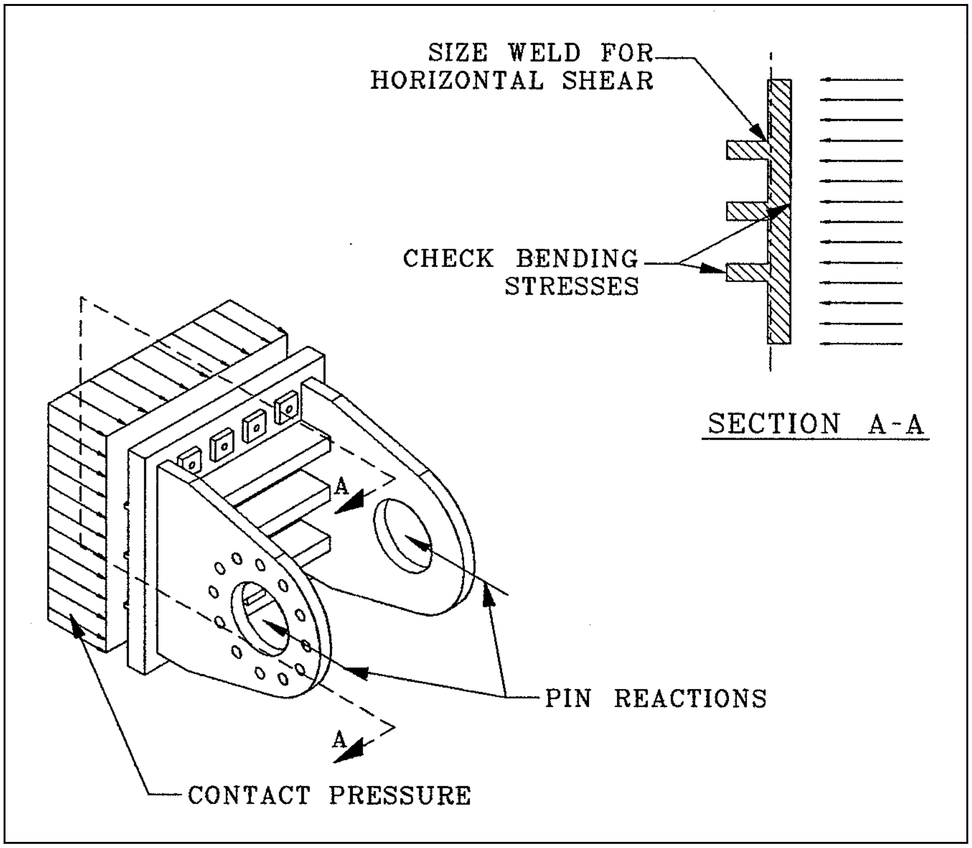

Figure 4-7. Design of base plate

maintenance-free bearings because friction is reduced, the lubrication acts as a seal to prevent dirt from entering the bearing, and corrosion protection is increased. Certain types of lubricants are detrimental to some maintenance-free bearings and other types of maintenance free-bearings should not be lubricated at all.

d. Bearing wear and deformation. Bearing size is a function of desired service life when designing for serviceability. Service life can be determined by use of empirical formulas and is based on magnitude and type of load, bearing movement, and expected contamination and corrosion. The manufacturer usually provides design procedures including empirical formulas and required safety factors. Angle of bearing tilt should be estimated for misalignments and gate movements based on judgement. Allowable angle of tilt of a spherical bearing is dependent upon bearing size, geometry, and design. The bearing manufacturer provides limits of tilt.

4-7. Design Details

a. Trunnion tolerance. Tolerances for the trunnion axis centerline with respect to the piers is based on clearance requirements between the side seal and seal plate embedded in the pier and between the gate bumper and the pier. If the trunnion centerline is not perfectly aligned, out-of-plane sweep (with respect to the pier) will occur when the gate is moved from the closed position to the fully raised position. Tolerance requirements may be relaxed if side-seal plates are terminated and a recess in the pier is provided above upper pool. The centerlines of trunnions at each gate arm must pass through a common axis to avoid unintentional friction loads due to binding as the gate rotates through its operational range.

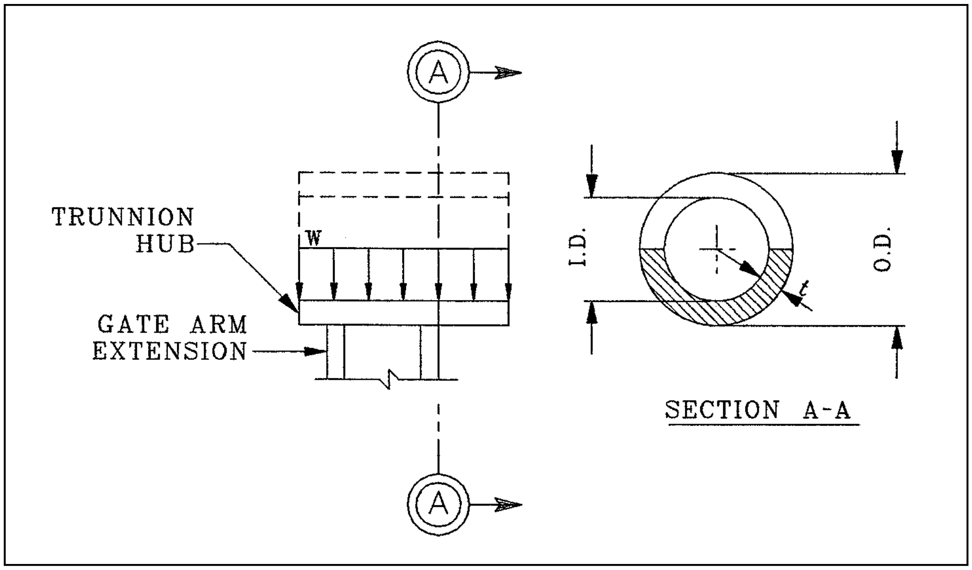

Figure 4-8. Trunnion hub design assumptions

Tolerance requirements should be determined based on gate size and should be included in project specifications.

b. Trunnion yoke adjustment. Horizontal and vertical jack screws are provided on the trunnion hub for setting and adjusting the trunnion yoke so that the trunnion hub axes are on a common horizontal line. Proper alignment is required to ensure that all cylindrical bearing surfaces of the yoke and hub rotate about a common horizontal axis without binding. Second-placement concrete or grout (zinc in the case of steel girders) can be used to fill the space between the trunnion girder and yoke and between the trunnion assembly and side bearing plate on the pier.

c. Bushings. Bushings are usually furnished with two side disk bushings and one cylindrical trunnion pin bushing. Shear pins between the side bushing and trunnion yoke plates are used to prevent bushing rotation. A light drive fit between the hub and cylindrical bushing is generally specified to prevent differential rotation between the hub and bushing. The bushing is usually given an overall finish of 1.6 μm (63 micro-in.) except for the bore finish of 0.8 μm (32 micro-in.).

d. Spherical bearings. Bearing rings that are mounted with an interference fit are positioned on the trunnion pin with spacers or shoulders placed against the inner ring. A housing shoulder is generally mounted to the trunnion pin on the side adjacent to the pier and a locking plate or spacer sleeve retains the ring on the opposite side. The housing end cover generally retains the outer ring. Retaining rings may be used to provide the bearings support along the axis of the pin. The bearing internal clearance (between inner and outer rings) must account for deformations induced by the interference fits. Figure 4-2 shows a typical spherical bearing arrangement.

e. Trunnion lubrication. For trunnion lubrication, grease grooves are commonly provided on the inside face of the bushing. The size, length, and location of the grease groove shall be sufficient to uniformly distribute lubricants to all bearing surfaces. This detailing shall be performed by the mechanical engineer. A hole may be drilled through the hub and bearing to inject the grease grooves with grease.

f. Trunnion pin. Trunnion pins may be designed with a hole drilled along the pin centerline for entry of a radioactive source to facilitate radiographic testing. The hole may also be tapped for handling, installation, and removal purposes.